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~~METHOD AND APPARATUS FOR CONTINUOUSLY SHIFTING PHASE OF AN ELECTRONIC SIGNAL~~

Background of the Invention

1. Field of the Invention

This invention relates to a method an apparatus for providing a continuously adjustable phase shift to an electronic signal.

2. Description of the Prior Art

Many methods of continuously phase shifting an electronic signal are known. Of the known methods, those which are capable of phase shifting a signal 180 degrees or more utilize cascaded stages which are each adjusted, or otherwise utilize expensive variable inductive or capacitive components, such as tapped delay lines.

Other methods of continuously shifting phase of a signal have utilized a variable resistor (pot) such as shown in Figure 1. The phase shift is accomplished by applying different phases of the signal to each end of the variable resistor, which allows a given phase between the two applied phases to be selected by in effect mixing a portion of each of the applied signals. Unfortunately, if the applied phases differ by 180 degrees the two components will exactly cancel thereby eliminating the output signal. More than 180 degree adjustment is not possible with this arrangement, as the

application of fixed phases of more than 180 degrees will add vectorially giving a range of less than 180 degrees. The aforementioned problem can be eliminated by various switching arrangements, one of which is shown in Figure 1, however this adds more expense, and requires that a switch be adjusted in addition to the pot.

A device called a goniometer solves all of the above problems quite nicely by providing a rotating coil inside of three or more stationary coils, the stationary coils being driven with different phases of the input signal. Thus, the rotating coil provides different output phases by being rotated to the appropriate position in proximity to the stationary coils. Unfortunately the cost of a goniometer is relatively high due to the coil construction, and the problem of coupling the output of the rotating coil member to the outside via slip rings or rotary transformer.

Other solutions to the problem include various electronic circuits such as phase locked loops, all pass filters and electronically variable delays, all of which are relatively complicated and expensive.

Summary of the Invention

The present apparatus and method for continuously shifting the phase of an electronic signal provides a resistive component having three or more primary connective means for receiving different fixed phases of the electronic signal which resistive component also has an adjustable connective means

which may be adjusted in its relative proximity to the primary connective means. Said resistive component may be continuous, allowing the adjustable connective means to be adjusted, in the same direction, past a given primary connective means a multiple number of times.

Other objects and a fuller understanding of this invention may be had by referring to the following description and claims, taken in conjunction with the accompanying drawings, in which:

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Figures 1 And B are ~~is a~~ diagrams showing two prior art devices;

Figure 2 is a diagram of a first embodiment of the invention;

Figure 3 is an alternate embodiment of Figure 2;

Figure 4 is a diagram of a second embodiment of the invention;

Figure 5 is a mechanical drawing of an embodiment of means 9;

Figure 6 is a further embodiment of the invention of Figure 4; ~~and~~

Figure 7 is an all electronic embodiment of the invention of Figure 4;

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Description of the Preferred Embodiments

Figure 1 is a diagram of two prior art devices to provide a phase shift to an input signal, the first device having a fixed phase shifter 1 operating on an input signal, and a variable resistor 2 operating to provide an output signal

which is a mixture or combination of the input and phase shifted input signal. The second prior art device of Figure 1 contains a fixed phase shifter 3, a switch 4 and a variable resistor 5, which variable resistor provides an output which is a mixture of phase shifted signals from 3 which have been selected by 4.

Figure 2 shows a first embodiment of the present invention having a fixed phase shift means 6A having an input responsive to the input signal and having three outputs, and a resistive component portion element or means 7A having four primary connective means 8a through 8d respectively, responsive to the input signal and the three outputs of the phase shifter respectively, the resistive means also having a variable connective means 11A, providing an output which is made up of portions of one or more of the signals applied to the four primary connective means.

Figure 3 shows an alternate embodiment of Figure 2 having a phase shifter 6B having two instead of three outputs, and a resistive means 7B corresponding to 7A.

Figure 4 shows a second embodiment of the present invention having a phase shifter means 6C similar to Figure 6A of Figure 2, and an inventive resistive means 9A of a continuous configuration, having four primary connective means 10a through 10d respectively, corresponding to 8a through 8d, and a further variable connective means 11B, corresponding to 11A, the variable connective means providing an output made up

of portions of one or more of the signals applied to the four primary connective means.

Figure 5 shows a mechanical drawing of an embodiment of inventive means 9A of Figure 4, showing a ceramic substrate 13, connective means 12a through 12d, resistive means 14 and adjustable connective means 11C.

Figure 6 shows a further embodiment of the invention having a ring counter type of phase shifter 6D, resistive means 9B the same as 9A of Figure 4, resonant circuit 15, and comparator 16.

Figure 7 shows still a further embodiment of the invention having a multiplier cluster composed of multipliers 17a through 17d, each having inputs 18a through 18d and 19a through 19d respectively, and having a common output 21, with four signal phases ØA through ØD shown connected to 18a through 18d respectively, which signal phases are provided by phase shifter 6E similar to 6C, and showing ~~multiple waveforms 20a through 20d which are supplied to 17a through 17d at inputs 19a through 19d respectively, and further showing~~ one method of generating waveforms 20a through 20d with a leaky integrator 22.

Referring to Figure 2, the input signal is applied to a primary connective means 8a at one end of the resistive means, with phase shifted versions of the input signal which are provided by the phase shift means 6A being applied in sequence to the remaining primary connective means 8b, 8c and 8d of the resistive means. The respective phases of the

preferred embodiment of Figure 2 being labeled by way of example. One skilled in the art will recognize that if the phases of the applied signal are all equally spaced, and the various primary connective means on the resistive means equally spaced, the phase of the output signal will be linearly dependent on the position of the variable connective means of the resistive means. For the phases given by way of example, a full 360 degrees of phase adjustment is provided. It will also be recognized that this phase control will be linear, providing the phase shifter outputs are of the proper phase, the primary connective means are properly placed, and the resistive means properly linear. While for convenience it is sometimes desirable to have such linearity of control of output phase, there is no such requirement for the operation of the present invention, and in fact such parameters as the phase of the output signals from 6A, the placement of the primary connective means on 7A and the linearity of 7A itself may differ from the suggested values by a significant amount, such differences not affecting basic operation of the invention.

One skilled in the art will recognize that under certain circumstances it will be desirable to build such differences into the invention. For example, if very fine resolution in the area of 180 degrees is desired, the 120 degree output could be changed to 150 degrees and the 270 degree output changed to 240 degrees. The same effect can also be had by changing the location of those primary connective means 8b and 8c corresponding to 120 and 270 degrees. There is

also no limitation on the number of primary or variable connective means to be used, as will be apparent to one skilled in the art, however four primary and one variable connective means will normally be adequate.

Figure 3 shows an alternate embodiment of Figure 2. Since the bottom connective means 8d of 7A is connected to the 360 degree output of 6A, for repetitive signals such as a CW sine wave, this 360 degree signal is the same as the 0 degree or input signal, accordingly, the bottom connective means 8d can be directly connected to the input.

Figure 4 shows another embodiment of the invention which has a continuous resistive means 9. The continuous resistive means will allow the variable connective means 11B to select any phase of output signal while being adjusted in one direction only. For example, the embodiment of Figure 2 must have the variable connective means moved across almost the entire resistive means to change from an output phase of 2 degrees to an output phase of 359 degrees. The embodiment of Figure 4 only requires a small movement. The ability to continuously shift the phase of the output signal without reversing the direction of adjustment being a significant advantage of the embodiment of Figure 4.

The continuous adjustment advantage of Figure 4 also has another use, that of frequency shifting the input signal. If the variable connective means 11B is caused to traverse the entire resistive means at a given rate, then the instant frequency of the output is the sum of the input frequency and

the variable connective means frequency, i.e. if the input frequency is 1000 Hz and the variable connective means is rotated at 5Hz, the output frequency will be 1005 Hz. This fact can be very useful in building frequency synthesizers or frequency modulators. By way of explanation, this operation contrasts a known circuit which utilizes a motor driven variable capacitor to tune an oscillator. The oscillator frequency is caused ~~used~~ to alternately increase and decrease as the capacitor plates are opened and closed by the motor. This oscillator generates a frequency which is responsive to the instant position of the motor shaft. If a motor were connected to the present invention of Figure 4, the output frequency would be responsive to the instant frequency of rotation of the motor shaft.

It may be noted that the resistive means 9A has four primary connective means 10a through 10d, rather than the minimum three which would be required. The reason for four is that the required phase angles of the applied signals are 90 degrees apart, which is very easy for the phase shifter 6C to generate, as compared to the 120 degree difference required for three primary connective means. The added cost of the extra connective means is therefor made up by the lower cost of the phase shifter 6C. Also, many oscillators have available quadrature outputs which would be suitably applied for ~~suitable for~~ such connective means.

The individual components required to build the embodiments of Figure 2 or Figure 3 are readily available to

one skilled in the art. The phase shifter 6A or 6B can be made of a tapped fixed delay line having delay times between taps corresponding to the desired phase shift. The resistive means 7A (7B) is a commercially available component referred to as a tapped potentiometer.

The phase shift means 6C of Figure 4 can be constructed from a tapped delay line as was 6A, but since the preferred phase angle between outputs is 90 degrees, tank circuits or active components can be utilized. Of particular interest is a digital system utilizing a master frequency which is divided by four in a ring or other counter, thus providing a signal at one fourth the frequency of the master, having all four phases available. This system is of considerable interest in the particular application of deriving the color subcarrier for the NTSC television system. The four times color subcarrier frequency is frequently used by television equipment manufacturers in their equipment, and thus readily available. Dividing the four times frequency by 4 to provide four quadrature signals for application to the resistive means 9A of Figure 4, is an easy task, thus cheaply developing a color subcarrier of continuously adjustable phase. This method is of great commercial value.

The resistive means 9A of Figure 4 is considered one of the inventive concepts of this application. It is believed that it is not presently known in the industry, or that it would have any practical use, other than that disclosed herein, if it were. Fortunately the means 9A of Figure 4 is similar to

7A of Figure 2, and it would be relatively easy for manufacturers of potentiometers to build a device which could be used for the means 9A.

Refer to Figure 5, which is a mechanical drawing of an inventive embodiment of means 9A of Figure 4. This continuous resistive means 9A for example, could be made of a ceramic substrate 13 with a circular deposit of conductive plastic or carbon film 14, as is presently done in the industry, except that the circular deposit 14 would be continuous, not broken. The circular deposit 14 would have four metallic contacts 12a through 12d, spaced at nominally 90 degrees, to make up the primary connective means of the resistive means, the contacts being of the same type now being used for potentiometers. The adjustable contact 11C would be the same as the wiper contact currently used in the industry.

It has been assumed for purposes of explaining the present invention that the phase shift means 6A, 6B and 6C are fixed. There is however no requirement of this in the present invention. As will be apparent to one skilled in the art, it would be possible to use variable phase shifters, or even to use an oscillator or other signal source. Further, the present invention could be used for any of the phase shifters, thus cascading devices.

The primary connective means and the variable connective means of the resistive means 7A and 9A as they have been described can be mechanical, however, there is no such restriction necessary for the operation of the present

invention, and such connective means can as well be made and adjusted by non-mechanical means, including but not limited to optical. In particular, analcg resistors, such as transistors and field effect transistors, photo resistors, and the like can be utilized as part of the resistive means, one embodiment of which is shown in Figure 7. Various multiplier circuits and devices could also be used.

Figure 6 shows an embodiment of the invention which uses a digital ring counter 6D for the phase shifter. The four digital outputs of the ring counter are applied to the continuous resistive means 9B as in Figure 4. The output of 9B is applied to a resonant circuit 15 which removes a substantial portion of the harmonic energy present on the signal due to the digital ring counter. The output of the resonant circuit, which is a sine wave, is applied to the input of a comparator 16. The other input of the comparator is a reference voltage which corresponds to the zero crossing voltage of the sine wave. The output of the comparator 16 is then a square wave which has a 50% duty cycle, and of course, this square wave may be a digital level signal.

Figure 7 shows an embodiment of the invention of Figure 4 where the mechanical resistive means 9A has been replaced with a group of electronic multipliers 17a through 17d. Various multiplier circuits are well known in the art. The Motorola MC 1494 and MC 1495 IC's are two well known components which can be utilized in implementing this multiplier function. The multipliers are identical in

operation. Each has an input 18a through d for its respective phase shifted signal from phase shifter 6E. That phase shifted signal is multiplied by a control voltage Ma-Md provided by control elements 23 which control voltage controls the percentage of its applied phase shifted signal ø which is passed by the multiplier to the common output 21. At any instant, one or two multipliers are active in order to provide a portion of one or two of the phase shifted signals to the common output 21. One skilled in the art will recognize that this operation is the same as that provided by 9A of Figure 4, except that there are no mechanical parts to be turned, so that the selection of the output phase is provided by purely electronic means. The use of electronic means makes available very high speed and long life operation, unlike the mechanical means which is limited in speed and life by the quality of the mechanical parts.

Figure 8 ~~7~~ also shows typical waveforms 20a through 20d of the control voltages Ma-Md with respect to equivalent rotation as referenced to the equivalent Figure 4, or time with respect to the addition ~~multiplication~~ of two frequencies. A method of generating one of the control waveforms with a leaky integrator 22 is also shown. The input to the leaky integrator is a square wave which could be generated with a ring counter such as 6D of Figure 6. The integrator output would ramp up while the square wave is present, and ramp (or leak) down when the square wave goes away. Using four leaky integrators one each on the four outputs of 6D will provide the four control waveforms Ma-Md required. Various other types of ramp

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generator circuits are well known in the art, and could be used for the ramp generating function. While shown specifically in an analog embodiment, it will be understood by one skilled in the art that digital implementations of any or all of the above described functions and means can be utilized. B6

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B5 > Although this invention has been described in its preferred form with a certain degree of particularity, it is understood that the present disclosure of the preferred form has been made only by way of example and that numerous changes in the details of construction and the combination and arrangement of parts may be resorted to as well as combinations of functions within or as part of other devices, without departing from the spirit and the scope of the invention as hereinafter claimed. Under the teachings of this invention, one skilled in the art will be able to combine various portions described with any of a number of known circuits or components to achieve substantially the same results.

16. (M What is claimed is: